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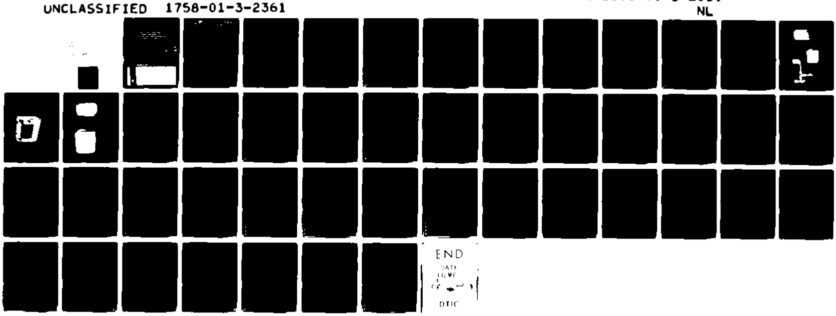

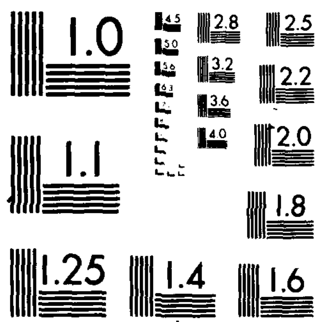

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Publication 1758-01-3-2361

FINAL SUMMARY REPORT

DOCUMENTATION OF MAINTENANCE AND SUPPORT REQUIREMENTS FOR TYPE B AND TYPE F WIND MEASURING AND INDICATING EQUIPMENT

October 1980

Prepared for
NAVAL AIR ENGINEERING CENTER
SHIP AND SHORE INSTALLATIONS ENGINEERING DEPARTMENT
LAKEHURST, NEW JERSEY 08733
under Contract N68335-79-C-2059

ARINC RESEARCH CORPORATION

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This report summarizes the results of a program for documentating maintenance and support requirements and identifying fleet problems associated with wind measuring and indicating equipment installed on Navy ships. The effort was performed by ARINC Research Corporation for the Ship and Shore Installations Engineering Department of the Naval Air Engineering Center (NAEC) Lakehurst, New Jersey. The period of performance was 1 October 1979 through 28 October 1980.

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FINAL SUMMARY REPORT 1 Oct 79-28 Oct 80

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DOCUMENTATION OF MAINTENANCE AND SUPPORT REQUIREMENTS FOR TYPE B AND TYPE F WIND MEASURING AND INDICATING EQUIPMENT,

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Prepared for

Naval Air Engineering Center
Ship and Shore Installations Engineering Department
Lakehurst, New Jersey 08733

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under Contract N68335-79-C-2059

by

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ABSTRACT

This report summarizes the results of a program for documenting maintenance and support requirements and identifiying fleet problems associated with wind measuring and indicating equipment installed on Navy ships. The effort was performed by ARINC Research Corporation for the Ship and Shore Installations Engineering Department of the Naval Air Engineering Center (NAEC) Lakehurst, New Jersey, under Contract N68335-79-C-2059. The period of performance was 1 October 1979 through 28 October 1980.

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CHAPTER ONE

INTRODUCTION

This final summary report highlights the activities and accomplishments of a program for documenting maintenance and support requirements for wind measuring and indicating equipment installed on Navy ships. The effort was performed by ARINC Research Corporation for the Ship and Shore Installations Engineering Department of the Naval Air Engineering Center (NAEC), Lakehurst, New Jersey, under Contract N68335-79-C-2059. The period of performance was 1 October 1979 through 28 October 1980.

1.1 BACKGROUND

All Navy ships are equipped with a wind measuring and indicating system that provides continuous visual indications of wind direction and speed as well as providing representative electrical signals for computation of flight deck crosswind and headwind conditions, computation of wind vectors for weapon launch systems, and record-keeping by meteorological equipment.

Errors in indications of wind direction and speed, or complete loss of these signals can have serious safety consequences. Several accidents and near accidents involving aircraft have been, in part, attributed to problems associated with the wind measuring and indicating equipment.

Many of the problems were reported to be the result of in-service maintenance and support deficiencies. In an attempt to minimize maintenance and support problems, NAEC is redefining and restructuring the maintenance concept so that in-service maintenance and support can be optimized. ARINC Research has assisted NAEC in this effort by conducting a program directed toward documenting maintenance and support requirements and identifying support problems associated with wind measuring and indicating equipment.

1.2 SCOPE

The effort performed during this program consisted of accomplishing tasks and subtasks directed toward the following:

- Development of a Maintenance Plan
  - Identification of Equipment Configuration and Data Acquisition
  - Preparation of Repairables/SM&R Code Listing
  - Determination of Maintenance and Support Requirements
  - Determination of Fleet Maintenance and Support Practices
  - Determination of Maintenance Philosophy
  - Preparation of Maintenance Plan
- Preparation of a Failure Criticality Analysis
  - Review of Functional Design
  - Review of Component and Piece/Part Usage Data
  - Identification of Failure-Significant Items
  - Definition of Failure Symptoms and Effects
  - Establishment of Levels of Severity
  - Determination of Failure Probabilities
  - Development of a Criticality Index
- Identification of Fleet Maintenance and Support Problems

1.3 DATA SUBMISSIONS

Data submissions during the contract period are listed in Appendix A.

CHAPTER TWO

EQUIPMENT DESCRIPTION

All Navy ships are equipped with a wind measuring and indicating system that provides continuous visual indications of wind direction (in degrees) and wind speed (in knots) relative to the ship's bow. The system also provides electrical signals representative of wind direction and speed for computation of flight deck crosswind and headwind conditions, computation of wind vectors for weapon launch systems, and record-keeping by meteorological equipment.

Currently there are approximately 400 active Navy and Coast Guard ships equipped with wind measuring and indicating systems. An additional 91 inactive Navy ships also have wind measuring and indicating systems.

There are two primary types of wind measuring and indicating systems used on ships -- Type B and Type F. Both systems operate by transmission of electrical synchro signals. The Type B system uses 60 Hz electric power, while the newer Type F system uses 400 Hz power. Equipments making up both the Type B system and the Type F system are manufactured by the Bendix Corporation, Environmental and Process Instruments Division, Towson, Maryland.

Both the Type B and Type F wind measuring and indicating systems include a detector, a transmitter, and an indicator (see Figure 1). On larger ships the system may include a wind direction and speed recorder unit (see Figure 2). On aircraft carriers (CVs) the system also includes a crosswind/headwind computer and crosswind/headwind indicator (see Figure 3).

System operation is dependent upon ship wiring and switching as well as on the individual units that make up the wind measuring and indicating system. Since most ships are equipped with multiple units in their respective wind measuring systems (i.e., starboard and port detectors, and forward and aft transmitters), a selector switch network is provided to permit a choice of units to be used, depending upon the situation.

Detailed technical data and specifications related to the Type B and Type F wind measuring and indicating equipment, the wind direction and

speed recorder, and crosswind/headwind computer and indicator are contained in the following Navy documents:

- NAVSHIPS 0365-262-5010 and MIL-W-15805, *Type B Wind Measuring and Indicating System*
- NAVSHIPS 0965-108-9010 and MIL-W-22900, *Type F Wind Measuring and Indicating System*
- NAVSHIPS 365-2761, *Wind Direction and Speed Recorder*
- NAVSHIPS 365-2815, *Crosswind/Headwind Computer and Indicator*

Material support spares for the wind measuring and indicating equipment used for ship installations are under the cognizance of the Ship Parts Control Center (SPCC), Mechanicsburg, Pennsylvania.

A very limited number of ships have yet a third type of wind measuring system. Units making up this system are derived from the AN/UMQ-5 Wind Measuring and Indicating System, which is identified and described in NAVAIR 50-30 FR-525. The system is used primarily for land-based installations, and material support is under the cognizance of the Aviation Supply Office (ASO), Philadelphia, Pennsylvania. Since the system is not intended or designed for ship installations, it was not included in this study. However, a brief discussion of the system is contained herein.

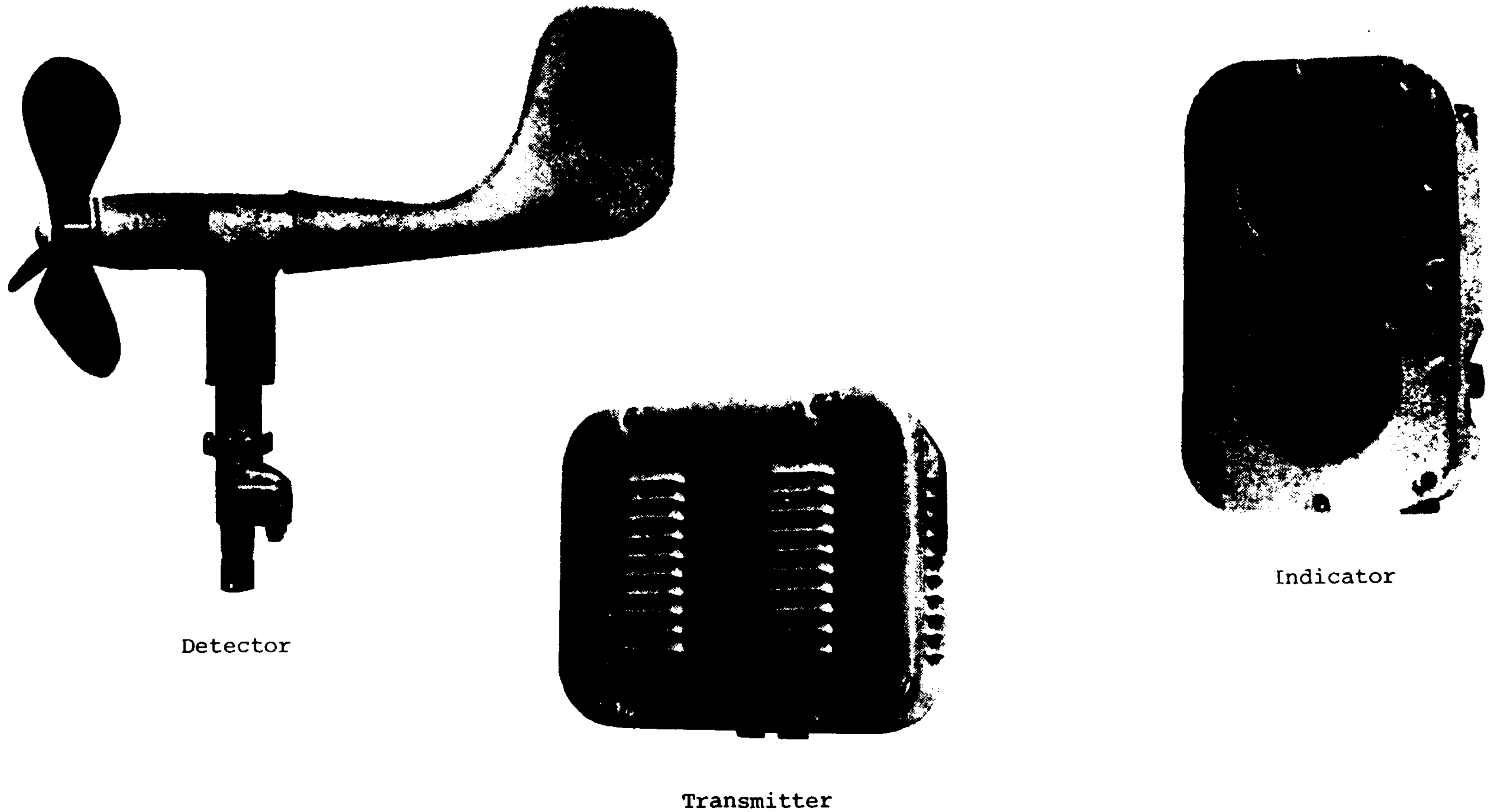


Figure 1. WIND MEASURING AND INDICATING EQUIPMENT

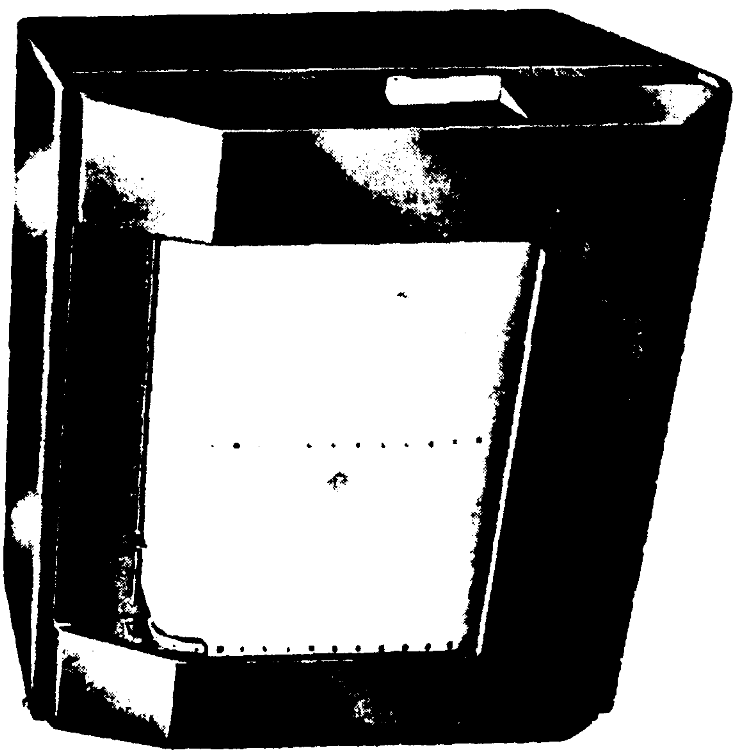
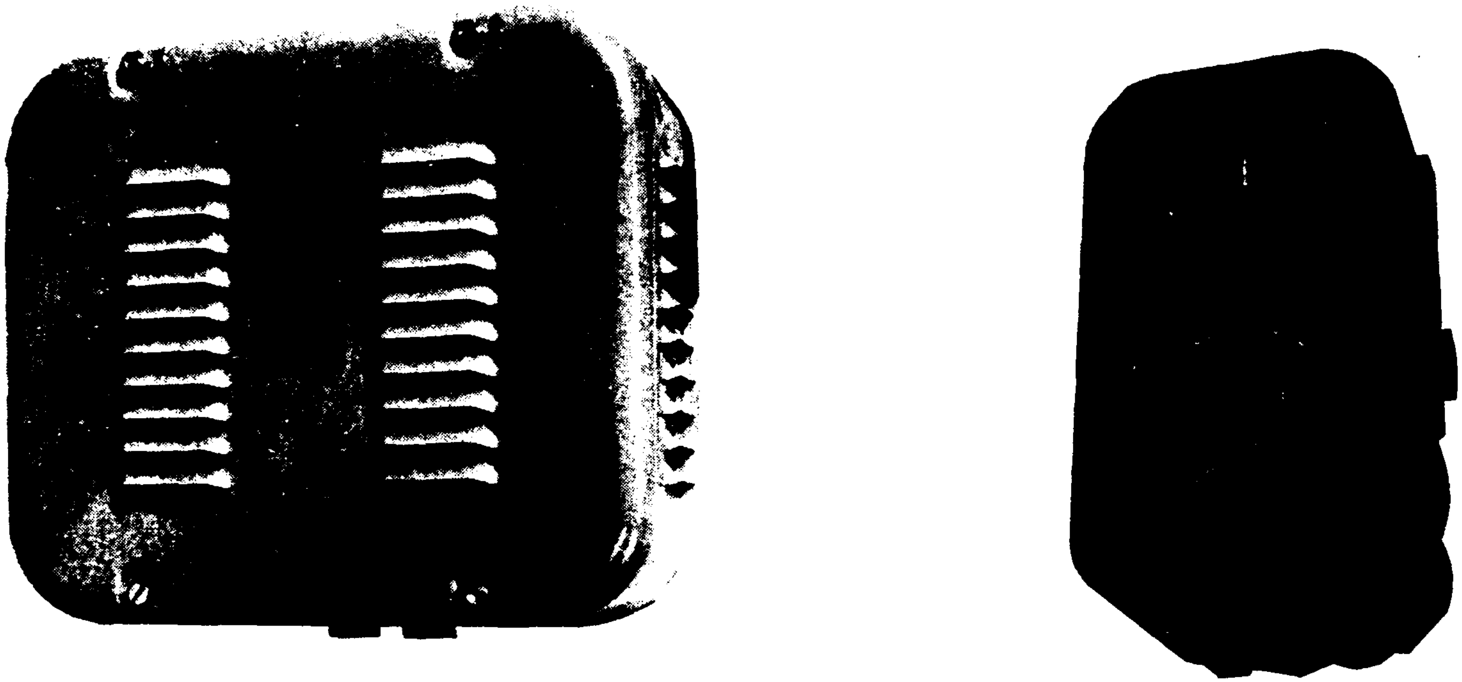


Figure 2. WIND DIRECTION AND SPEED RECORDER



Computer

Indicator

Figure 3. CROSSWIND/HEADWIND COMPUTER AND CROSSWIND/HEADWIND INDICATOR

CHAPTER THREE

MAINTENANCE PLAN DEVELOPMENT

ARINC Research prepared a Maintenance Plan setting forth the maintenance requirements for the wind measuring and indicating system and submitted it to NAEC in preliminary form in April 1980. The final version, dated 10 September 1980, was submitted to NAEC in October 1980. The Maintenance Plan and maintenance requirements contained therein were developed in general accordance with OPNAVINST 4790.2, OPNAVINST 4790.4, COMNAVSURFPACINST 4700.1, COMNAVSURFLANTINST 9000.1, and Data Item Description UDI-L-21013. Some deviations were necessary because of administrative differences between the Naval Air Systems Command (NASC) and the Naval Sea Systems Command (NSSC), and differences in provisioning procedures used by SPCC.

Since NSSC and SPCC do not use the standard WUC (Work Unit Code) used by NASC for indentured breakdown identification of equipment, it was necessary to establish an indentured breakdown based on the four-character Equipment Identification Code (EIC), LH07 for the wind measuring and indicating equipment. The EICs assigned in Part II of the Maintenance Plan were extended to a maximum of seven characters to facilitate an indentured breakdown. On certain ships the EIC has been extended to a maximum of eight characters to identify the position of unit installation. This code system, however, varies from ship to ship, and therefore does not provide for a consistent indentured equipment breakdown to identify repairable units, assemblies, and subassemblies.

Additionally, the provisioning of spares aboard ship by SPCC is accomplished by a quantitative index called a best replacement factor (BRF)* in lieu of the gross removal factor (GRF) used by ASO; therefore, usage data, where presented, are based primarily on BRF data.

Since the wind measuring and indicating equipment has been in service for many years, usage data are generally not provided in Part II of the Maintenance Plan as current fleet usage data apply. Exceptions to this

*The provisioning of spares aboard ship by SPCC is based on a quantitative index called a best replacement factor (BRF). The BRF represents the experienced yearly demand rate for an item. Should the BRF equal or exceed 0.25 for a vital item or piece/part of a vital next higher assembly, the item will normally be provisioned aboard ship.

include items that must be procured that were not previously identified as integral items. Estimates of usage factors for those items are based on the individual item's component and piece/part BRFs.

The *Wind Measuring and Indicating System Maintenance Plan* is identified by the Naval Air Engineering Center as publication NAEC 002-80 and by ARINC Research as publication 1758-01-1-2324.

The maintenance philosophy of the Maintenance Plan is discussed in the following paragraphs.

3.1 MAINTENANCE PHILOSOPHY

The maintenance and support concepts for the wind measuring and indicating system resulting from the findings of this program will not necessitate significant changes from the current maintenance philosophy.

The following paragraphs describe the maintenance and support practices for subassemblies, assemblies, and units of the system as a function of the level of maintenance. Detailed information regarding repair, maintenance requirements, and support equipment is contained in the *Wind Measuring and Indicating System Maintenance Plan*.

3.1.1 Organizational-Level Maintenance

Organizational-level maintenance includes all scheduled and corrective maintenance activities performed aboard a ship by the ship's personnel. Organizational-level maintenance of the wind measuring and indicating system will be accomplished by ship's company rated as interior communications (IC) electricians on all classes of ships.

3.1.1.1 Scheduled Maintenance

Scheduled or planned maintenance actions at the organizational level will be performed in accordance with the applicable maintenance index page (MIP) and maintenance requirement card (MRC). Scheduled maintenance activities will include cleaning, inspection, lubrication, alignment and adjustment, and operational and functional testing of units making up the wind measuring system.

Selected major combatant ships will be equipped with a built-in test unit that will provide a functional check of the wind measuring and indicating system as it is required.

The wind measuring and indicating system on ships not equipped with built-in test will be functionally checked by means of portable test units at designated Naval bases.

3.1.1.2 Corrective Maintenance

Corrective maintenance at the organizational level consists of operational and functional test, fault isolation, and unit repair by assembly, subassembly, component, or piece/part replacement, and assembly repair by subassembly, component, or piece/part replacement. Some instances of repair are limited to removal and replacement only. Specific organizational-level corrective maintenance repair activities include the following:

- Detector - Organizational repair of both the Type B and Type F detectors and constituent assemblies is accomplished by component and piece/part replacement and alignment as required. Spare components and piece/parts provisioned on board ship are identified in APL 381510034 for the Type B detector and APL 381510065 for the Type F detector. In addition, a spare detector unit is provisioned on major aviation ships, including all CV, LHA, and LPH type ships.

- Transmitter - Organizational repair of both the Type B and Type F transmitters and their respective wind direction and wind speed assemblies is accomplished by subassembly, component, and piece/part removal and replacement, and alignment or adjustment as required. Spare subassemblies, components, and piece/parts provisioned on board ship are identified in APL 381510035 for the Type B transmitter, and APL 381510066 for the Type F transmitter.

  The wind speed assembly in both the Type B and Type F transmitter units contains a roller-disc integrator subassembly. This subassembly is complex and is subject to maintenance-induced damage. As a result, organizational-level maintenance of the integrator is limited to removal and replacement of the subassembly. Corrective maintenance involving disassembly of the roller-disc integrator subassembly is accomplished at the intermediate maintenance activity or depot. Other subassemblies in the transmitters that organizational-level personnel are authorized only to remove and replace include the servo-amplifier and magnetic amplifier. The servo-amplifier is repaired at the intermediate level and the magnetic amplifier is not repairable since it is encapsulated.

  Complete wind direction and wind speed assemblies will be provisioned as spare items on selected major combatant missile firing and aviation-capable ships having only single transmitters in their wind measuring and indicating systems.

- Indicator - Organizational repair of indicator units is accomplished by component and piece/part replacement and alignment as required. Spare components and piece/parts provisioned on board ship for repair of indicator units are identified by the following APLs:

APL 381510070	Type F/60 Indicator
APL 381510036	Type B Indicator
APL 381510004	Type B Indicator

- Crosswind/Headwind Computer - Organizational repair of the crosswind/headwind computer is accomplished by subassembly, component, and piece/part removal and replacement, and adjustment or alignment as required. Spare subassemblies, components, and piece/parts provisioned on board ship are identified in APL 381510064.

  Subassemblies that organizational-level personnel are authorized only to remove and replace include two servo-amplifier subassemblies and a dc power supply. Those units are repaired at the intermediate level.

- Crosswind/Headwind Indicator - Organizational repair of the crosswind/headwind indicator is accomplished by component and piece/part removal and replacement. Spare components and piece/parts provisioned on board ship are identified in APL 381510063.

- Wind Direction and Speed Recorder - Organizational repair of the wind direction and speed recorder is accomplished by component and piece/part removal and replacement, and alignment and adjustment as required. Spare components and piece/parts provisioned on board ship are identified in APL 381510060.

3.1.2 Intermediate-Level Maintenance

Intermediate-level maintenance of the wind measuring and indicating equipment is performed at shore-based intermediate maintenance activities (SIMAs) and aboard tenders. SIMAs currently responsible for repair of wind measuring and indicating equipment are located at Charleston, South Carolina; Little Creek, Virginia; Mayport, Florida; Pearl Harbor, Hawaii; and San Diego, California. Intermediate maintenance activities are staffed by Navy IC electricians and are authorized to perform all repair tasks necessary to return wind measuring and indicating equipment to a serviceable condition.

Corrective maintenance capabilities at the SIMA consist of complete functional test, fault isolation, repair, and alignment and adjustment for all units, assemblies, and subassemblies making up the wind measuring system. Repair is accomplished to the component or piece/part level by removal and replacement.

Subassemblies and components that are beyond the capability of repair at the organizational level are repaired at the intermediate level by removal and replacement of defective piece/parts. These subassemblies include the roller-disc integrators used in the Type B and the Type F transmitters, the servo-amplifier used in the Type B transmitter and crosswind/headwind computer, the dc power supply used in the crosswind/headwind computer, and the microammeters used in the crosswind/headwind indicator. Intermediate-level maintenance activities can also perform minor repairs on components such as synchros and motors; e.g., replacement of brushes or bearings.

To expedite equipment turnaround time under emergency conditions, or to facilitate unit repair at times when lengthy piece/part waiting times are encountered, certain assemblies are provisioned in limited

quantities for insurance purposes at the SIMAs. These items include the speed mechanism assembly and shaft housing assembly in both the Type B and Type F detectors, and the wind direction and wind speed assemblies in the Type B and Type F transmitter units.

3.1.3 Depot-Level Maintenance

Depot-level maintenance of the wind measuring and indicating equipment includes restoring the operating and performance characteristics of the equipment to its original design and technical specifications (Class B repair or overhaul) and calibration of all end items, including units, repairable assemblies, subassemblies, and components coded for depot repair or found to be beyond the capability of intermediate maintenance activities.

Depot calibration consists of adjusting and aligning the wind measuring equipment to standard specifications so that any unit or plug-in assembly may be integrated into a wind measuring system and operate in an accurate and precise manner without degrading system performance. Depot calibration requires a "hot bench" with units and assemblies of the wind measuring system available and maintained as secondary standards. Each end item to be repaired and calibrated is incorporated into the remainder of the system (the secondary standards) and adjusted and aligned accordingly.

The Norfolk Naval Shipyard and the Long Beach Naval Shipyard are designated for repair and overhaul of wind measuring and indicating equipment.

3.2 SYNCHRO SIGNAL AMPLIFIER

Larger combatant ships have requirements to drive more receivers than the wind direction and speed transmitter is capable of accommodating. To enable a transmitter unit to drive more indicators, computers, and recorders, the outputs of the transmitter unit are coupled to a synchro signal amplifier unit. Synchro signal amplifiers are essentially master repeaters used to increase the capacity of the transmitter synchro. The synchro amplifier unit accepts a synchro signal from a remote transmitting synchro and, through use of a servo system, aligns its own output transmitting synchros with the input and retransmits the signal to other equipment. Typically, two synchro amplifiers are used in conjunction with a single transmitter, one for wind direction and the other for wind speed.

Several different types of synchro signal amplifier units are employed with the wind measuring and indicating equipment. Many of these units are quite old, using vacuum tube electronic circuits, while some of the newer units have solid-state circuits. Some of the synchro signal amplifier units recently or currently employed with the wind measuring and indicating system include the Mk 2, Mod 1; Mk 7, Mods 2A and 4A; and Mk 27, Mods 7, 7A, 8, and 8D. However, the wind measuring and indicating system does not include a synchro signal amplifier unit in its normal equipment complement and there is no amplifier specifically dedicated for operation with the system. Consequently a specific synchro amplifier could not be identified in the Maintenance Plan.

3.3 AN/UMQ-5 WIND MEASURING AND INDICATING SYSTEM

During the performance of this program, NASC (Code 5512F) received a request from Minesweeper MSO 429 for direction in obtaining a replacement detector for its Wind Measuring and Indicating System. The detector to be replaced was identified as a Model ML 400B and initially some difficulty was experienced in identifying the unit and the system of which it was a part. An investigation revealed the unit to be part of the AN/UMQ-5 Wind Measuring and Indicating System, which is identified and described in NAVAIR 50-30 FR-525, dated January 1957. The system is used primarily for land installations and is under the cognizance of ASO. It has no APL nor does the unit appear on a COSAL. Normally, this system is not used in shipboard installations, and the design of units making up the system is different from the standard Type B and F systems used for shipboard installations.

The system was manufactured by Bendix-Friez Instrument Division (currently the Bendix Corporation, Environmental and Process Instruments Division) in Towson, Maryland; however, none of the units making up the system have been manufactured since the 1960s.

Following is a list of the units making up the AN/UMQ-5 Wind Measuring and Indicating System and their respective NSNs:

Designation	Nomenclature	NSN
ML 400	Detector	2R 6660 00-557-5639
ML 400B	Detector	2R 6660 00-531-5051
ML 400C	Detector	2R 6660 00-650-2463
ID 300B	Indicator, Speed	2R 6660 00-530-3482
ID 300C	Indicator, Speed	2R 6660 00-556-1895
ID 586	Indicator, Direction and Speed	2R 6660 00-527-9496
RD 108B	Recorder	2R 6660 00-552-0095
MT 535	Mount	2R 6660 00-223-7338

Several ships of the AGS and MSO type use units derived from the AN/UMQ-5 system. Requests have been processed from some of these ships for ML 400 Detectors. Although the ML 400 Detector is no longer in production, a similar (and interchangeable) unit is being manufactured: the Bendix Aerovane Transmitter Model 120. The transmitter unit in the Aerovane system is the same unit that is called the detector in the UMQ-5 and in the Type B and F systems. The primary difference between the ML 400 Detector and the Aerovane Transmitter Model 120 is that the ML 400 contained a 5HG synchro in its wind direction circuit and could drive five or six receivers, while the Aerovane Transmitter Model 120 contains a 1HG synchro and can drive only two or three receivers.

Because the system was not intended for shipboard installations and only a limited number of ships have units derived from the AN/UMQ-5 system, detailed maintenance requirements for the system are not covered in the maintenance plan; however, a brief discussion of the system and identification of its constituent units is provided in the maintenance plan.

3.4 NEW ASSEMBLY/SUBASSEMBLY PROCUREMENT REQUIREMENTS

Changes in spares support requirements brought about by the maintenance plan were discussed with SPCC personnel, including the program manager and inventory manager for the wind measuring and indicating equipment. SPCC agreed with the changes in the support philosophy; however, it was indicated that before any assemblies or subassemblies not previously identified as integral items can be procured, engineering drawings or specifications must be provided. Assemblies and subassemblies for which drawings will be required are identified as follows:

- Speed Mechanism Assembly, Detector, Type B and Type F
- Housing and Shaft Assembly, Detector, Type B and Type F
- Wind Direction Assembly, Transmitter, Type B and Type F
- Servo-Amplifier Subassembly, Transmitter, Type B, and Crosswind/Headwind Computer
- Wind Speed Assembly, Transmitter, Type B and Type F
- Roller-Disc Integrator Subassembly, Transmitter, Type B and Type F
- Wind Direction and Speed Assembly, F/60 Indicator
- DC Power Supply, Crosswind/Headwind Computer

ARINC Research and NAEC representatives met with cognizant manufacturer personnel and the necessary action is being taken to satisfy the above requirements.

3.5 BUILT-IN TEST

Selected major combatant ships will be equipped with a built-in test unit that will provide for functional checking of the wind measuring and indicating system. The unit will provide standard wind direction and speed signals that will give operating personnel a "push to test" capability. This should increase their confidence in the system by enabling them to quickly detect an error resulting from gradual drift in alignment or adjustment that could otherwise go unnoticed. Also, the built-in test unit incorporates differential synchros to permit the output of individual detectors to be offset, thus compensating for intrinsic wind error resulting from ship's structure in the area of the detectors.

The wind measuring and indicating system on ships not equipped with built-in test units will be functionally checked using portable test units at designated Naval bases, or the indications from the port and starboard detector may be compared to see if they differ unreasonably.

3.6 SCHEDULED MAINTENANCE (PMS) PROCEDURES

Scheduled or planned maintenance actions are performed at the organizational level in accordance with the applicable maintenance index page (MIP) and maintenance requirement card (MRC). Scheduled maintenance activities include cleaning, inspection, lubrication, alignment and adjustment, and operational and functional testing of units making up the wind measuring system. The most recent MIP and MRC control numbers for specific scheduled maintenance activities on wind measuring units and the required intervals are as follows:

- Detector; Clean, Inspect, and Lubricate
  MIP: IC-6/45-59; MRC: 87 3STH N; dated August 1977
  Frequency: Semi-annual
- Transmitter; Clean, Inspect, and Lubricate
  MIP: IC-6/145-59; MCR: 65 2UEK N; dated June 1975
  Frequency: Semi-annual
- Indicator; Clean and Inspect
  MIP: IC-6/172-47; MRC: 47 3NMQ N; dated April 1977
  Frequency: Annual
- Crosswind/Headwind Computer; Clean, Inspect, and Lubricate
  MIP: IC-6/134-28; MRC: A1 1EJP S; dated October 1971
  Frequency: Semi-annual
- Crosswind/Headwind Indicator; Clean, Inspect, and Lubricate
  MIP: IC-6/134-28; MRC: 28 3VRY Y; dated February 1978
  Frequency: Semi-annual
- Recorder; Clean, Inspect, and Lubricate
  MIP: IC-6/172-47; MRC: 63 1NSY N; dated June 1973
  Frequency: Quarterly
- System; Port and Starboard Detector Comparison Check
  MIP: IC-6/145-59; MRC: 65 2UEL N; dated June 1975
  Frequency: Semi-annual

There are an additional six individual MIP/MRC control numbers listing virtually the same scheduled maintenance procedures for the detector and transmitter units. These procedures are redundant and outdated and, therefore, were not listed.

A preliminary review of the scheduled maintenance procedures revealed significant discrepancies. Typical discrepancies include the following:

- Improper unit identification

- Excessive disassembly requirements resulting in maintenance-induced damage
- Inadequate procedural detail resulting in improper reassembly, adjustment, and alignment
- Inappropriate lubrication requirements for sealed bearings

The scheduled maintenance procedures should be reviewed in detail and be updated to reflect the maintenance philosophy of the maintenance plan as well as to correct procedural discrepancies.

3.7 TECHNICAL PUBLICATIONS AND DOCUMENTATION

During ARINC Research's performance of this program, we used the applicable technical manuals extensively. Generally, the manuals contain a considerable amount of pertinent information; however, some errors and inconsistencies were noted and details are lacking in terms of disassembly, reassembly, and alignment and adjustment. Although the technical publications are generally adequate and are not as important at this time as the scheduled maintenance procedures, when the actions resulting from the Maintenance Plan have been implemented, all applicable technical publications and documents should be reviewed for errors and deficiencies, and revised accordingly.

CHAPTER FOUR

FAILURE RATE DETERMINATION

ARINC Research determined failure rates for all individual components and piece/parts making up the system's failure-significant items.* For the most part, normalized annual BRF data were acquired from SPCC, although in several instances alternate sources including manufacturers and the Failure Rate Data (FARADA) Program were used. Since component or piece/part replacements are directly related to equipment failures, it was postulated that the replacement rate or BRF of a given item very closely approximated the actual failure rate for the item. These data were used to derive normalized annual failure rates for the individual failure-significant items and their related assemblies and units as shown in Table 1. Many of the failure-significant items listed in Table 1 contain multiple piece/parts. An estimate of the overall failure rate for the item consists of determining the sum of the individual failure rates. These failure rates are shown in Table 1, failure rate column number one ($\lambda 1$). This procedure is adequate in many instances; however, when attempting to determine the failure rate for a complex mechanical assembly, one of the fallacies of using the sum of the individual failure rates becomes apparent -- the problem of dealing with multiple and/or secondary failures. In an attempt to increase the validity of the quantitative portion of this analysis, each complex failure-significant item underwent a design review. On the basis of our engineering judgment of the review, we made a decision relating to dominant failures and interdependencies associated with coincident failures. The rationale associated with these decisions is discussed in detail in Appendix B. The resulting failure rates are shown in Table 1, failure rate column number two ($\lambda 2$). Those failure-significant items that were reviewed are identified by footnotes on the $\lambda 2$ column. The footnotes identify the rationale or explanation in Appendix B.

The failure rates shown in $\lambda 1$ represent a worst-case condition while those failure rates in $\lambda 2$ are considered to be more representative of what will actually occur.

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*A failure-significant item is defined as any component, piece/part, or integral piece/parts group having a demonstrated failure rate that significantly degrades equipment reliability and creates a need for a replacement or repair action.

Table 1. FAILURE-SIGNIFICANT ITEMS		
Item	Failure Rate λ1	Failure Rate λ2
Detector, Type B	2.041	1.671
Rotor Assembly, Wind Speed	0.100	0.100
Gear Train, Wind Speed	1.028	0.944 [1]*
Synchro, Wind Speed	0.028	0.028
Electrical Contact/Slip Ring Assembly	0.129	0.093 [2]
Vane Assembly	0.003	0.003
Bearings, Vane Shaft	0.690	0.440 [3]
Synchro, Wind Direction	0.028	0.028
Connector	0.035	0.035
Detector, Type F	1.366	0.920
Rotor Assembly, Wind Speed	0.100	0.100
Gear Train, Wind Speed	0.359	0.199 [4]
Synchro, Wind Speed	0.025	0.025
Electrical Contact/Slip Ring Assembly	0.129	0.093 [2]
Vane Assembly	0.003	0.003
Bearings, Vane Shaft	0.690	0.440 [3]
Synchro, Wind Direction	0.025	0.025
Connector	0.035	0.035
Transmitter, Type B	2.477	1.702
Wind Direction Assembly	0.511	0.481
Synchro, Control Transformer	0.100	0.100
Inductor	0.003	0.003
Transformer	0.008	0.008
Amplifier, Servo	0.247	0.247 [5]
Motor, Reversible	0.023	0.023
Gear Train	0.089	0.059 [6]
Synchro, Transmitter	0.031	0.031
Connector	0.010	0.010
Wind Speed Assembly	1.966	1.221
Synchro, Receiver	0.028	0.028
Gear, Spur	0.050	0.050
Motor, Synchronous	0.130	0.130
Integrator Subassembly	1.136	0.892 [7]
Gear Train	0.581	0.080 [8]
Synchro, Transmitter	0.031	0.031
Connector	0.010	0.010
Transmitter, Type F	2.318	2.002
Wind Direction Assembly	0.494	0.404
Synchro, Control Transformer	0.021	0.021
Amplifier, Magnetic	0.036	0.036
Motor, Servo	0.200	0.200
Gear Train	0.120	0.030 [9]
Synchro, Transmitter	0.029	0.029
Synchro, Transmitter	0.078	0.078
Connector	0.010	0.010

*See Appendix B for footnotes.

(continued)

Table 1. (continued)			
Item	Failure Rate λ1	Failure Rate λ2	
Wind Speed Assembly	1.824	1.598	
Synchro, Control Transformer	0.021	0.021	10
Gear Train	0.095	0.078	
Motor, Synchronous	0.110	0.110	
Amplifier, Magnetic	0.036	0.036	
Motor, Servo	0.140	0.140	
Relay	0.260	0.260	11
Integrator Subassembly	1.039	0.830	
Synchro, Transmitter	0.029	0.029	
Gear	0.006	0.006	
Synchro, Transmitter	0.078	0.078	
Connector	0.010	0.010	
Indicator, Type F/60	0.109	0.109	
Synchro, Receiver, Wind Direction	0.050	0.050	
Synchro, Receiver, Wind Speed	0.050	0.050	
Connector	0.009	0.009	
Crosswind/Headwind Computer	1.391	1.211	
Wind Speed Circuit	0.776	0.686	
Synchro, Control Transformer	0.100	0.100	
Inductor	0.003	0.003	
Transformer	0.008	0.008	5
Amplifier, Servo	0.247	0.247	
Motor, Reversible	0.023	0.023	9
Gear Train	0.120	0.030	
Potentiometer, Linear	0.047	0.047	
Transformer	0.006	0.006	12
Power Supply, DC	0.222	0.222	
Wind Direction Circuit	0.615	0.525	
Synchro, Control Transformer	0.100	0.100	
Inductor	0.003	0.003	
Transformer	0.008	0.008	5
Amplifier, Servo	0.247	0.247	
Motor, Reversible	0.023	0.023	9
Gear Train	0.120	0.030	
Potentiometer, Sine-Cosine	0.096	0.096	
Connectors	0.018	0.018	

CHAPTER FIVE

FAILURE CRITICALITY ANALYSIS

Accurate and reliable operation of wind measuring and indicating equipment is vital to ship operations. Errors in indications of wind direction and speed, or complete loss of these signals can have serious safety consequences. Several accidents and near accidents involving aircraft have been, in part, attributed to problems associated with the wind measuring and indicating equipment. Tests have shown that wind direction errors as small as 10° have degrading effects on carrier landings for some types of aircraft.

To better define these problems we performed a failure criticality analysis to identify those failure modes having an effect on safety. The analysis involved a functional review of the system design and the effect of outputs on ship operations. It was concluded that failures affecting safety applied primarily to aircraft operations. Safety-impact failures were defined as component or piece/part failures whose behavioral characteristics cause erroneous wind direction and speed indications that cannot be readily identified (e.g., the indicated and actual wind directions are different but the equipment appears to be operating normally). We identified a second level of failure that consisted of those component and piece/part malfunctions that render the system, or the affected portion of the system, inoperative. This type of failure is easily identified and appropriate corrective action can be taken.

The detailed results of the analysis have been published under separate cover, *Failure Criticality Analysis for Type B and Type F Wind Measuring and Indicating Equipment,* dated October 1980.

The results of the analysis identified 10 items used in 17 applications having a potential safety impact. These individual items and the respective applications are shown in Table 2 along with their normalized annual failure rate (λ) and probability of occurrence (P_O). Failure rates were derived from SPCC normalized annual replacement factors (BFRs) and the failure probability of occurrence from the following equation:

$$P_O = 1 - e^{-\lambda t}$$

where: λ equals the failure rate, and
t equals the time (1 year in this case)

Table 2. FAILURE-SIGNIFICANT ITEMS HAVING A POTENTIAL SAFETY IMPACT

Item	P_O	λ	Application							
			DTB	DTF	TTB		TTF		CHC	
					WD	WS	WD	WS	WD	WS
Synchro, Control Transformer	0.095	0.100			X				X	X
Potentiometer, Sine-Cosine	0.092	0.096							X	
Synchro, Transmitter	0.075	0.078					X	X		
Potentiometer, Linear	0.046	0.047								X
Synchro, Transmitter	0.031	0.031			X	X				
Synchro, Transmitter	0.029	0.029					X	X		
Synchro, Wind Direction	0.028	0.028	X							
Synchro, Wind Direction	0.025	0.025		X						
Synchro, Control Transformer	0.021	0.021					X	X		
Vane Assembly	0.003	0.003	X	X						

P_O - Probability of occurrence of a single failure of one item over a one-year period
λ - Normalized annual failure rate
CHC - Crosswind/Headwind Computer
DTB - Detector, Type B
DTF - Detector, Type F
TTB - Transmitter, Type B
TTF - Transmitter, Type F
WD - Wind Direction Circuit
WS - Wind Speed Circuit

All of the identified items have failure modes that will provide erroneous wind indications that are not readily recognizable and give the appearance that the system is functioning normally. Failures affecting safety primarily involve synchros and analog computational devices, where failure frequently involves loss of mechanical or electrical alignment, or wiring problems where an output signal is still present, but in error.

An additional 31 items were identified, accounting for 51 applications, that can render the system inoperable (see Table 3); however, these failures are easily recognizable and are therefore not considered to affect safety.

Table 3. FAILURE-SIGNIFICANT ITEMS (NO SAFETY IMPACT)

Item	P_o	λ	Application							
			DTB	DTF	TTB		TTF		CHC	
					WD	WS	WD	WS	WD	WS
Gear Train, Wind Speed	0.611	0.944	X							
Integrator Subassembly	0.590	0.892				X				
Integrator Subassembly	0.564	0.830						X		
Bearings, Vane Shaft	0.356	0.440	X	X						
Relay	0.229	0.260						X		
Amplifier, Servo	0.219	0.247			X				X	X
DC Power Supply	0.199	0.222								X
Motor, Servo	0.181	0.200					X			
Gear Train, Wind Speed	0.180	0.199		X						
Motor, Servo	0.131	0.140						X		
Motor, Synchronous	0.122	0.130				X				
Motor, Synchronous	0.104	0.110						X		
Rotor Assembly, Wind Speed	0.095	0.100	X	X						
Slip Ring Assembly	0.089	0.093	X	X						

P_o - Probability of occurrence of a single failure of one item over a one-year period
λ - Normalized annual failure rate
CHC - Crosswind/Headwind Computer
DTB - Detector, Type B
DTF - Detector, Type F
TTB - Transmitter, Type B
TTF - Transmitter, Type F
WD - Wind Direction Circuit
WS - Wind Speed Circuit

(continued)

Table 3. (continued)

Item	P_o	λ	Application							
			DTB	DTF	TTB		TTF		CHC	
					WD	WS	WD	WS	WD	WS
Gear Train, Disc Drive	0.077	0.080				X				
Gear Train, Wind Speed	0.075	0.078						X		
Gear Train, Servo	0.058	0.059			X					
Gear Spur, Spur	0.049	0.050				X				
Amplifier, Magnetic	0.035	0.036					X	X		
Connector	0.034	0.035	X	X						
Gear Train, Servo	0.030	0.030					X		X	X
Synchro, Wind Speed	0.028	0.028	X			X				
Synchro, Wind Speed	0.025	0.025		X						
Motor, Servo	0.023	0.023			X				X	X
Synchro, Control Transformer	0.021	0.021						X		
Connector	0.010	0.010			X	X	X	X		
Connector	0.009	0.009							X	X
Transformer	0.008	0.008			X				X	X
Transformer, Power	0.006	0.006								X
Gear	0.006	0.006						X		
Inductor	0.003	0.003			X				X	X

P_o - Probability of occurrence of a single failure of one item over a one-year period
λ - Normalized annual failure rate
CHC - Crosswind/Headwind Computer
DTB - Detector, Type B
DTF - Detector, Type F
TTB - Transmitter, Type B
TTF - Transmitter, Type F
WD - Wind Direction Circuit
WS - Wind Speed Circuit

CHAPTER SIX

MATERIAL SUPPORT

When cognizance for the wind measuring and indicating equipment was transferred from NSSC to NASC, one of the first problems encountered involved material support. The Navy was concerned that the Defense Logistics Agency was procuring incorrect components and piece/parts, but the foremost problem was the unavailability of assets ready for issue (RFI).

6.1 ACQUISITION OF INCORRECT WIND INTENSITY ROTORS

Following the transfer of responsibility for the wind measuring equipment to NASC it was learned that fleet personnel ordering replacement wind intensity rotors by the appropriate NSN were receiving rotors that would not fit the Type B and Type F detectors. It was discovered that replacement wind intensity rotors for the Bendix Type B and Type F wind measuring equipment were being procured by the Defense General Supply Center (DGSC) in Richmond from the Belfort Instrument Company in Baltimore. The replacement rotors manufactured by Belfort are designed for the Belfort wind measuring system -- the replacement rotors, although similar, cannot be physically interchanged with the Bendix rotors as the hub diameter is different. This situation brought about concern that other piece/parts were being procured similarly from Belfort for the Bendix systems. We interviewed Messrs. J. Riley and H. James of Belfort regarding interchangeability between the Belfort system and the Bendix Type B and F systems. Mr. James, head of engineering, said that none of the Belfort assemblies are interchangeable with Bendix Type B and F systems. The Belfort anemometer uses a tachometer/generator in its wind speed circuit and the equipment design is totally different. Further, the Belfort anemometer transmits wind speed and direction data directly to the indicators without using a unit of the type that Bendix calls a transmitter. Hence, aside from the rotor assembly, which is almost identical, procurement by DGSC of any other assemblies from Belfort should not be a problem to the Navy because the units are totally different from the Bendix equipment and would not be inadvertently supplied. Future procurement of rotors under NSN 9G 6660-00-123-0072 should be Bendix P/N 511501-3 (Type B) or P/N 1136348-3 (Type F). Although the Type B and Type F part numbers are different, the rotor assemblies are identical and interchangeable.

6.2 UNAVAILABILITY OF SPARE UNITS

During the period of performance of this program the inventory responsibility for units making up the wind measuring and indicating system was transferred within SPCC. At the time of transfer it was found that a large quantity of assets were in a non-RFI condition, which undoubtedly appravated the problem of unavailability of spare units over the past two years. Non-RFI assets included 60 Type B detectors, 24 Type B transmitters, 71 Type F detectors, and 20 Type F transmitters. The new inventory manager, Mrs. C. Tenney, has taken the necessary action to get more than half of these units into the overhaul and repair cycle. Also, where required, she has processed or is processing new procurements. Table 4 presents the current issue and procurement status of wind measuring and indicating units.

Table 4. WIND MEASURING AND INDICATING UNIT STATUS

Nomenclature	Non-RFI	Under Repair	Under Contract	Awaiting Award	Two-Year Demand	Active Population
Detector, Type B	22	38		94	121	331
Transmitter, Type B	12	12	17		61	243
Detector, Type F	41	31	55	63	138	402
Transmitter, Type F	8	12	37	22	98	347

Delivery of units currently under contract (i.e., Type B and F detectors, and Type F transmitters) will commence in mid-1981, while those units awaiting contract award will be available in early 1982. These procurement actions along with the repair of non-RFI units should alleviate much of the spares problem experienced during the past two years.

6.3 SHIPBOARD PIECE/PART SUPPORT

A factor compounding the material support problem and contributing to the large accumulation of non-RFI units backed up in the supply system was revealed when an investigation was performed to determine what items are authorized in the spares complement onboard Navy ships in support of the Type B and Type F detectors and transmitters. APLs were used to identify the spare items and the quantity of each authorized (given in the APL as a function of the number of respective units on each ship). SPCC computer tabulations provided data on the number of active ships currently in operation and the quantity of units on each. Specific cost data on individual

spare items were retrieved from the DLSC Navy Management Data List (Navy 0-268/80).* The results of the investigation are summarized in Table 5. The table identifies the spare item (nomenclature and NIIN) complement for the individual units and the authorized quantity of spares per ship as a function of the number of units on board the ship. Also shown is the cost of each individual spare item and the associated total or fleet-wide cost for provisioning the item on operational Navy ships. Examination of the table reveals that the range of authorized spares is very limited. In fact, the 26 ships equipped with single Type F detectors are authorized no spare piece/parts. If one considers only those ships having no more than two units (which constitutes over 98 percent of the Navy's operational ships) the spares complement is only 19 line items: 5 for the Type B detector, 8 for the Type B transmitter, 2 for the Type F detector, and 4 for the Type F transmitter. The total instantaneous fleetwide cost of authorized shipboard spare piece/parts in support of the detectors and transmitters at any point in prior years has been only $143,056, and 78 percent of that has been in support of the Type F transmitter.

Although the spare piece/part support posture is changing with the transfer of responsibility for wind measuring and indicating equipment, the above situation emphasizes the need for reassessing the material support requirements for the wind measuring and indicating system.

*Cost information presented in the Navy Management Data List represents cost at the time of last procurement and may not be current.

Table 5. AUTHORIZED SHIPBOARD SPARE PARTS FOR TYPE B AND TYPE F DETECTORS AND TRANSMITTERS

NOMENCLATURE	NIIN	QTY PER SHIP 1	2	3	≥4	ITEM COST ($)	TOTAL COST ($)
Detector, Type B	Number of ships	27	142	2	3		10,255
O-Ring	00-194-3710			1	1	<1	5
Washer	00-558-3312			1	1	3	15
Bearing	00-425-0909			3	3	4	60
Bearing	00-198-2925	1	1	1	1	2	348
Bearing	00-198-2928	3	6	6	6	2	1926
Rotor	00-213-0072		1	1	1	50	7350
O-Ring	00-051-6865		1	1	1	<1	147
O-Ring	00-222-2767	1	1	1	1	<1	174
Shaft, Rotor	00-713-5585			1	1	46	230
Transmitter, Type B	Number of ships	163	37	2	0		11,127
Bearing	00-198-2921		4	4		1	156
Motor AC	00-500-2487		1	1		58	2262
Gear	00-517-1975		1	1		11	429
Gear	00-517-1973	1	1	1		7	1414
Gear	00-690-2937			1		44	88
Gear	00-330-9248		1	1		58	2262
Gear	00-690-2938			1		25	50
Gear	00-541-5630		1	1		21	819
Roller, Disc	00-572-2140		1	1		21	819
Disc	00-932-3712	1	1	1		14	2828
Detector, Type F	Number of ships	26	184	1	1		10,094
Washer	00-558-3312			1	1	3	6
Bearing	00-756-1431		1	1	1	3	558
Bearing	00-425-0909			3	3	4	24
Bearing	00-802-4523			2	2	3	12
Contact Assy	00-713-5582				1	35	35
Shaft, Rotor	00-055-6115			1	1	46	92
Gear	00-056-2386				1	9	9
Gear	00-056-2387				1	29	29
Gear	00-056-2388				1	5	5
Screw, Captive	00-334-9010				1	7	7
Connector	00-259-3420				1	17	17
Rotor	00-213-0072		1	1	1	50	9300
Transmitter, Type F	Number of ships	75	132	1	1		111,580
Roller, Disc	00-056-2390		1	1	1	21	2814
Roller, Shaft Assy	00-056-2389	1	1	1	1	69	14421
Gear	00-056-2391				1	44	44
Gear	00-215-7799				1	11	11
Gear	00-215-7805				1	27	27
Gear	00-089-2111				1	30	30
Motor, Servo	00-052-3529			1	1	323	646
Motor, AC	00-975-4011				1	149	149
Semiconductor	00-881-9398				1	1	1
Spring	00-056-2392				1	3	3
Amplifier, Mag	00-055-6117	1	1	1	1	270	56430
Synchro	00-852-2369		1	1	1	274	36716
Synchro	00-898-1393				1	185	185
Synchro	00-928-5593				1	98	98
Bearing	00-100-6158				1	3	3
Switch Sens	00-646-4619			1	1	1	2

CHAPTER SEVEN

FLEET MAINTENANCE AND SUPPORT PROBLEMS

The following findings of problems relating to maintenance, support, and operation of wind measuring and indicating equipment are based on ARINC Research Corporation's observations and investigation of current maintenance practices and interviews with cognizant Navy personnel.

Some of the personnel responsible for maintenance of the wind measuring and indicating system lack specific technical knowledge of the equipment and do not keep the equipment adjusted or aligned to ensure accurate operation. The system frequently receives low maintenance priority and in some isolated instances preventive maintenance procedures were signed off without being accomplished. This situation results in users losing confidence in the wind direction and speed indications provided by the equipment.

Factors contributing to this situation, at least in part, include a lack of Navy schooling on the wind measuring and indicating equipment (not even a formal OJT program exists) and the absence of a Navy enlisted classification (NEC) identifying wind measuring and indicating equipment within the IC electrician rating. These two factors support the opinion that the wind measuring and indicating system is unimportant.

An additional problem relating to the lack of confidence in the wind measuring and indicating system is the inherent influence of ships' structures on the airflow in the vicinity of the detectors and the resultant error. This problem has been assessed on some ships and found to be significant. Errors as large as eight degrees between the actual wind direction and that indicated by the wind measuring and indicating system have been identified and appear to be common.

The Navy has also experienced problems resulting from inadequate standardization and quality control of equipment repaired by the depot. In some instances, equipment described as being RFI has been drawn from the supply system with misaligned synchros, reversed synchro leads, and synchros with attachment hardware not properly secured. This type of problem is further compounded by personnel making changes to ship's wiring to compensate for equipment wiring problems and not properly documenting the change.

Corrective maintenance on the wind measuring and indicating equipment carried out by untrained and inexperienced personnel sometimes results in misalignment or improper adjustment and reassembly of components and assemblies. This situation results in improper operation or premature or immediate failure, requiring that the entire unit be sent to a higher level of maintenance. Of particular concern is the wind speed assembly in both the Type B and Type F transmitter units. This assembly contains the roller-disc integrator subassembly, which is the most complex single mechanism in the system and the most prone to inadvertent maintenance-induced damage. Such damage is induced not only by corrective maintenance, but by preventive maintenance as well.

Some organizational personnel have been selectively removing components and piece/parts from units being returned to higher maintenance levels. These components and piece/parts are subsequently used for equipment repairs when spare parts are not available. This process, although appearing to resolve an immediate spares deficiency, compounds the problem. Repairs accomplished with cannibalized components and piece/parts do not place demands on the supply system. As a result the cognizant inventory managers within SPCC and DLA, who acquire and allocate spares on the basis of demand, are not informed of those demands. Consequently, the spares deficiency problem becomes regenerative and future spares allocations are even more deficient.

CHAPTER EIGHT

RECOMMENDATIONS

ARINC Research considers the following recommendations to be significant in the resolution of current deficiencies and the implementation of an improved maintenance and support program for the wind measuring and indicating equipment:

- Develop a recommended shipboard spares parts provisioning list in accordance with the Maintenance Plan including repairable and consumable items, for submission to SPCC.
- Maintain close coordination with SPCC to ensure expeditious overhaul and repair of remaining non-RFI assets.
- Provide a spare detector unit on board all major aviation ships including CV, LHA, and LPH type ships.
- Provide a spare transmitter wind direction assembly and wind speed assembly on major combatant missile-firing and aviation-capable ships having single transmitters.
- Terminate shipboard repair of the following subassemblies and provision spares on board ship:
  - Roller-Disc Integrator (TTB and TTF)
  - Servo Amplifier (TTB and CHC)
  - DC Power Supply (CHC)
- Complete development of the built-in test unit. The worst-case failure mode of the wind measuring and indicating system is when the indicated and actual wind direction differ, but the wind system appears to be operating in a normal manner. The built-in test unit will resolve the problem of identifying erroneous wind data. The built-in test unit should include differential synchros to compensate for inherent wind errors resulting from ship's structures in the vicinity of the detectors.
- Complete development of the portable test unit.
- Review and update scheduled maintenance procedures to include the maintenance philosophy of the Maintenance Plan, the correction of procedural discrepancies and deficiencies, and the addition of alignment, adjustment, and disassembly/reassembly procedures.

- All applicable technical documents and publications should be reviewed for deficiencies and revised to reflect all changes.
- Establish a training program providing group and individual instruction, with hands-on training as required, to train IC electricians on wind measuring and indicating equipment.
- A ship's wind measuring and indicating system is vitally important to air operations and to weapon launch systems. The absence of a specific Navy enlisted classification (NEC) within the IC electrician rating is one of the factors currently reinforcing the opinion that the wind measuring and indicating system is unimportant. It is recommended that consideration be given to taking the necessary action to establish an NEC within the IC rating identifying the wind measuring and indicating system.
- A one-time investigation of ships' wiring relating to the wind measuring and indicating system should be conducted, and the wiring standardized to correspond to the equipment design. This activity involves a point-to-point wiring check that is now necessary to define and resolve undocumented changes made through the years to accommodate nonstandardized switching network and equipment problems; i.e., reversed synchro leads. The resulting wiring configuration should be documented and controlled in the future.

APPENDIX A

DATA SUBMISSIONS

The following data were submitted under Contract N68335-79-C-2059.

Item No.	Item	Date Submitted	Submitted To
1	Preliminary Configuration Listing	10/11/79	NAEC Code 91223
2	First Progress Letter	12/12/79	NAEC Code 91221
3	Bendix Drawing Package	12/14/79	NAEC Code 91223
4	Second Progress Letter	1/17/79	NAEC Code 91221
5	Maintenance Philosophy	1/18/79	NAEC Code 91223
6	Third Progress Letter	4/02/80	NAEC Code 91221
7	Preliminary Maintenance Plan Draft	4/13/80	NAEC Code 91223
8	Reliability Requirements Information for New Wind Measuring Equipment	4/23/80	NAEC Code 5512F
9	Preliminary Usage Data Analysis	6/04/80	NAEC Code 91223
10	Fourth Progress Letter	6/19/80	NAEC Code 91221
11	Fifth Progress Letter	7/29/80	NAEC Code 91221
12	Trip Report, Meeting with SPCC	9/10/80	NAEC Code 91223
13	Final Maintenance Plan	10/24/80	NAEC Code 91223

APPENDIX B

RATIONALE FOR DEVELOPING FAILURE RATE ESTIMATES FOR SELECTED ITEMS OF THE WIND MEASURING AND INDICATING SYSTEM

Selected failure-significant items making up the wind measuring and indicating system contain multiple piece/parts whose individual replacement rates can be used to estimate the failure rate of the overall item. In some instances a reasonable estimate of the failure rate is represented simply by the sum of the individual replacement rates or BRFs. However, when attempting to develop a failure rate estimate for a complex mechanical assembly, consideration must be given to multiple or coincident failure situations (e.g., failure of one gear in a reduction gear train can cause secondary failure of all the intermeshing gears). To accommodate this multiple failure situation within complex mechanical assemblies, the design was reviewed and the item was divided, as required, into groups of components whose failures are interdependent. These groups are referred to as interdependent failure groups. Engineering judgment was used to identify dominant piece/parts whose replacement rate would represent the group failure rate. The intent of the approach was to provide a more realistic result from simply using the sum of the individual replacement rates or BRFs. The rationale used in making these determinations, for items footnoted in Table 1, is discussed in this appendix. Footnote 1 in Table 1 is discussed in Section 1, footnote 2 is discussed in Section 2, footnote 3 is discussed in Section 3, etc.

1. GEAR TRAIN, WIND SPEED, DETECTOR, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Shaft, Rotor (-5)*	0.060	
(2)	Gear, Spur (-16)	0.024	0.880
(3)	Bearing, Ball, 2 each (-11)	0.880	
(4)	Gear Assembly (-70)	0.030	0.030
(5)	Shaft, Pinion (-69)	0.020	0.020
(6)	Gear, Spur (-17)	0.014	0.014
		Total	0.944

*Dash numbers in parentheses are the item identification numbers found on the respective engineering drawings.

Items 1, 2, and 3 form an interdependent failure group whose individual BRFs are overshadowed by a very high replacement rate for the bearings that support the rotor shaft. Engineering judgment suggests that the failure of a rotor shaft or spur gear will most likely be accompanied by bearing replacement, either because of an impending bearing failure, or on a preventive basis. Therefore, the bearing replacement rate will be dominant, including consideration of multiple failures. As a result, we postulate that the replacement rate for the bearings will be the failure rate (λ) for the group. The basic BRFs for the remaining items are included individually with the overall sum and provided as an estimate of the wind speed gear train's normalized annual failure rate.

2. ELECTRICAL CONTACT/SLIP RING ASSEMBLY, DETECTOR, TYPE B AND TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Contact Assembly (-56, -63)	0.054	0.054
(2)	Rings, Collector, 6 each	0.036	0.039
(3)	Washer, Insulating, 5 each	0.039	
		Total	0.093

Items 2 and 3 form an interdependent failure group of two individual parts types whose failure and subsequent corrective maintenance actions are interdependent; i.e., failure of a collector ring will generally involve replacement of at least one, and sometimes two of the adjacent insulators. It is therefore postulated that the slightly higher demand rate for the insulator washers accommodate a multiple failure, or multiple replacement, and the dominant BRF for the insulator will be the failure rate of the slip ring assembly. Adding the contact assembly's BRF to that of the slip ring yields an estimate of the electrical contact/slip ring assembly's normalized annual failure rate.

3. BEARINGS, VANE SHAFT, DETECTOR, TYPE B AND TYPE F

The vane shaft of the Type B and Type F detectors is supported by an upper and lower bearing. The lower bearing (BRF = 0.440) requires replacement approximately twice as frequently as the upper bearing (BRF = 0.250). A worst-case failure rate would be the sum of the two bearing replacement factors (0.690); however, this does not take into consideration the fact that when the upper bearing does fail, the lower bearing will most likely be replaced, either because of a failure, or on a preventive basis. A more realistic estimate of the failure rate for the vane shaft bearings is based on the postulation that the replacement rate of the lower bearing will be dominant and include the multiple failure case. Therefore, the normalized annual failure rate is 0.440.

4. GEAR TRAIN, WIND SPEED, DETECTOR, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Shaft, Rotor (-7)	0.073	
(2)	Gear, Spur (-16)	0.038	0.090
(3)	Bearing, Ball, 2 each (-90)	0.090	
(4)	Gear Assembly (-46)	0.029	
(5)	Shaft, Pinion (-45)	0.020	0.086
(6)	Bearing, Ball, 2 each (-12)	0.086	
(7)	Gear, Spur (-17)	0.023	0.023
		Total	0.199

Items 1, 2, and 3 and items 4, 5, and 6 form two similar interdependent failure groups. In both cases the dominant failure is the bearings supporting the shaft and gear. Thus, it is postulated that the higher demand rate for the bearings, in both cases, represents the normalized annual failure rate for the individual groups.

5. AMPLIFIER, SERVO

The failure rate for the servo amplifier was estimated on the basis of the sum of the BRFs for the individual piece/parts (see below):

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Transistor (1133548), 4 each	0.216	0.216
(2)	Diode (1132837), 2 each	0.012	0.012
(3)	Resistor, Fixed (RC20GF122K)	0.005	0.005
(4)	Resistor, Fixed (RC20GF470K)	0.007	0.007
(5)	Resistor, Fixed (1133549)	0.007	0.007
		Total	0.247

6. GEAR TRAIN, WIND DIRECTION, TRANSMITTER, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear (-216)	0.030	0.030
(2)	Gear Assembly (-215)	0.030	
(3)	Gear (-220)	0.029	0.029
		Total	0.059

The wind direction gear train in the Type B transmitter forms an interdependent failure group in which two individual gears (items 1 and 3) intermesh with a duplex idler gear assembly (item 2). Failure of items 1 or 3 will generally affect item 2. As a result, the sum of the three

BRFs for the individual gears would yield an unrealistically high estimate of the gear train's failure rate. However, since the duplex idler gear is common to both of the other two gears, it may be assumed that the failure rate of the idler will be accommodated by the sum of the individual failure rates of the two adjacent gears. Hence, the normalized annual failure rate for the gear train is estimated to be 0.059.

7. INTEGRATOR SUBASSEMBLY, WIND SPEED, TRANSMITTER, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear Assembly (-22)	0.049	0.049
(2)	Gear, Duplex (-70)	0.036	
(3)	Shaft Assembly (-30)	0.092	0.092
(4)	Roller, Disc Drive	0.190	0.190
(5)	Disc, Driving, 2 each (-58)	0.320	
(6)	Spring (-56)	0.043	0.320
(7)	Bearing, Ball (-61)	0.020	
(8)	Retainer (-60)	0.027	
(9)	Gear, 2 each (-62)	0.053	
(10)	Gear Assembly (-37)	0.220	0.220
(11)	Shaft (-36)	0.065	
(12)	Switch, Limit (-11)	0.021	0.021
		Total	0.892

Items 1, 2, and 3 constitute the wind speed input gear train and shaft assembly for the integrator. Item 2, a duplex gear, intermeshes with gear 1 and the spiral gear end of the shaft assembly (3). Failure of items 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the two adjacent gears.

Items 5 through 8 form the disc mechanism interdependent failure group. The dominant piece/part failure rate of the mechanism is associated with the drive discs; it is virtually an order of magnitude greater than the rate for any other component. Engineering judgment suggests that failure of any of the other components making up the mechanism (bearings, retainer, and spring) will be accompanied by an impending failure of the drive discs. Hence, the failure rate of the drive discs is assumed to accommodate multiple failures and represents the failure rate of the disc drive mechanism.

Items 9, 10, and 11 constitute an interdependent failure group of the internal disc drive gear train. Item 10, a duplex drive gear, intermeshes with items 9 and 11 and is the dominant failure component in the gear train by a significant margin. Its failure rate is postulated to accommodate the multiple failure case and represents the overall ambiguity group.

BRFs for the remaining items are included with the sum of the failure rates of interdependent failure groups to provide an estimate of the integrator's normalized annual failure rate.

8. GEAR TRAIN, SYNCHRONOUS MOTOR

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear, Spur	0.057	0.057
(2)	Gear, Idler, Duplex (-69)	0.094	
(3)	Gear (-63)	0.110	0.110
(4)	Shaft (-67)	0.020	0.020
(5)	Gear (-65)	0.300	0.300 (0.080)*
		Total	0.487 (0.267)*

The synchronous motor gear train in the wind speed assembly of the Type B transmitter provides the constant speed input to the integrator's disc mechanism. Item 2, a duplex idler gear, intermeshes with two adjacent gears (items 1 and 3). Failure of items 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the two adjacent gears.

The basic BRFs for the remaining two items are included with items 1 and 3 to provide an estimate of the gear train's failure rate.

The gear identified as item 5, with a BRF of 0.300, intermeshes with a gear assembly internal to the integrator (see Section 7, item 10), which has a replacement rate of 0.220. Engineering judgment indicates that these two gears experience coincident failures nearly three-fourths of the time. Although the individual replacement rates must be acknowledged for independent consideration of the synchronous motor gear train and integrator subassembly, the degree of failure interdependency must be considered in any determination of a failure rate for the overall wind speed assembly. The independent failure rate of the gear (representing its contribution to the overall failure rate of the wind speed assembly) is estimated to be $0.300 - 0.220 \cong 0.080$.

9. GEAR TRAIN, WIND DIRECTION, TRANSMITTER, TYPE F

The wind direction gear train in the Type F transmitter consists of four individual intermeshing gears. The gears each have a BRF of 0.030, and the failure of any single gear will subsequently cause secondary failure of adjacent gears. As a result of this relationship, the normalized annual failure rate of the gear train is estimated to be 0.030 rather than the sum of the four individual BRFs.

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*Independent gear failure rate contribution to the failure rate of the overall wind speed assembly.

10. GEAR TRAIN, WIND SPEED INPUT, TRANSMITTER, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear	0.009	0.009
(2)	Gear, Duplex	0.017	
(3)	Gear	0.023	0.023
(4)	Gear	0.046	0.046
		Total	0.078

The wind speed gear train provides the wind speed input to the integrator. Item 2, a duplex gear, intermeshes with two adjacent gears (items 1 and 3). Failure of item 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the failure rates of the two adjacent gears.

The basic BRF for the remaining gear is added to items 1 and 3 to provide an estimate of the gear train's normalized annual failure rate.

11. INTEGRATOR SUBASSEMBLY, WIND SPEED, TRANSMITTER, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear Assembly (-246)	0.057	0.350
(2)	Shaft Assembly, Roller (-243)	0.350	
(3)	Disc, Driving (-267)	0.320	0.320
(4)	Spring (-266)	0.043	
(5)	Bearing, Ball (-270)	0.020	
(6)	Retainer (-268)	0.027	
(7)	Gear, 2 each (-265)	0.027	0.100
(8)	Gear Assembly (-274)	0.100	
(9)	Gear Assembly (-271)	0.035	
(10)	Gear Spur (-273)	0.018	0.018
(11)	Switch, Limit, Maximum (-239)	0.021	0.021
(12)	Switch, Limit, Minimum (-239)	0.021	0.021
		Total	0.830

Items 1 and 2 constitute the integrator's wind speed input gear and shaft assembly. Any failure of the input gear assembly will affect the shaft assembly or mating gear in the wind speed input gear train external to the integrator. As a result, the shaft assembly will exhibit the dominant failure rate and accommodate failure of the gear assembly.

Items 3 through 6 form an interdependent failure group representing the disc mechanism identical to that in the Type B integrator. The rationale for estimating the disc mechanism's normalized annual failure rate is given in Section 7.

Items 7, 8, and 9 constitute an interdependent failure group of the integrator's internal disc drive gear train. Item 8 intermeshes with the two other gears (items 7 and 9) and is the dominant failure component. Its failure rate is postulated to accommodate the multiple failure case and, therefore, represents the group.

The basic BRFs for the remaining piece/parts are included with the estimated failure rates for the interdependent failure groups and combine to yield an overall estimate of the Type F integrator subassembly's failure rate.

12. DC POWER SUPPLY, CROSSWIND/HEADWIND COMPUTER

The failure rate for the dc power supply was estimated to be the sum of the BRFs for the individual piece/parts (see below):

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Transistor 1141924	0.041	0.041
(2)	Transistor 1137227	0.040	0.040
(3)	Transistor 1137187	0.008	0.008
(4)	Diode 1N538, 4 each	0.012	0.012
(5)	Diode 1136792-3	0.014	0.014
(6)	Diode 1136605, 4 each	0.028	0.028
(7)	Resistor, WW RW59V271	0.017	0.017
(8)	Resistor, Vari RA10LASD101A	0.006	0.006
(9)	Resistor, WW RW59V501	0.007	0.007
(10)	Resistor, Fixed RC20GF395J	0.009	0.009
(11)	Resistor, Fixed RC20GF681J	0.007	0.007
(12)	Resistor, Fixed RC20GF3R9J	0.007	0.007
(13)	Capacitor 1136779	0.011	0.011
(14)	Thermistor	0.012	0.012
(15)	Thermistor	0.003	0.003
		Total	0.222